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ScienceDirect
Renewable and Sustainable Energy Reviews
11 (2007) 1827–1842
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Role of BCHP in energy and environmental sustainable development and its prospects in China

Xiaoli Hao[a,b,*], Guoqiang Zhang[b], Youming Chen[b]

[a]*College of Energy and Safety Engineering, Hunan University of Science and Technology, Xiangtan, Hunan 411201, PR China*
[b]*College of Civil Engineering, Hunan University, Changsha, Hunan 410082, PR China*

Received 22 December 2005; accepted 23 December 2005

Abstract

During last century, worldwide environment degradation gets more and more serious, and achieving environmental sustainable development is desirable. As many environmental issues are directly or indirectly energy related, energy sustainable development is one of the most important prerequisites for environmental sustainable development. Renewable energy technologies and energy conservation are two solutions for energy sustainable development. At present, energy-saving technology is a feasible and an effective way to achieve energy and environmental sustainable development, although renewable energy may be final solution to environmental issues. Building cooling, heating, and power (BCHP) technology, which usually use natural gas as primary energy, has high efficiency of energy utilization due to the utilization of distributed power generation and heat recovery, and thus is a promising energy conservation technology. BCHP can reduce pollutants emission and thus protects the environment besides improving IAQ and increasing reliability of building energy supply. As the largest developing country, China is just in the process of adjusting energy structure and improving energy efficiency. Because of its significant role in energy and environmental sustainable development, developing BCHP in China will help the country in optimizing energy proportion, increasing energy efficiency, and protecting environment. Therefore,

*Corresponding author. College of Energy and Safety Engineering, Hunan University of Science and Technology, Xiangtan, Hunan 411201, PR China. Tel.: +86 732 8290835.
E-mail address: xlhao@hnust.edu.cn (X. Hao).

1364-0321/$ - see front matter
doi:10.1016/j.rser.2005.12.007

BCHP technology will have broad prospects in China and it will promote the country's energy and environmental sustainable development.

Keywords: Energy and environmental sustainable development; Environmental impact; Renewable energy; Energy conservation; BCHP; China

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Contents

1. Introduction

It has not been a long time since sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. However, sustainability has attracted much attention in recent years due to huge pressure from population growth, economic development, environmental pollution, and climate change [2–6]. The public, researchers, and policy-makers are much more aware of the importance of sustainable development than before.

Energy and environment are two main aspects of sustainable development. Worldwide industrialization has been accompanied by environmental degradation. During past 100 years, environmental degradation has become more and more serious. The three most important global environmental issues are acid precipitation, stratospheric ozone depletion, and global climate change, which are all related with extraction, transportation, and utilization of energy resource directly or indirectly. Thus, energy sustainable development is one of the most important prerequisites for environmental sustainable development.

Two potential solutions to energy sustainable development are renewable energy technologies and energy conservation. From the long-term viewpoint, utilization of

renewable energy should be a final solution for sustainable development. However, most of the current renewable energy technologies, e.g. solar, wind energy, etc., have low energy utilization efficiency and high expense, and thus cannot compete with conventional fossil energy with respect to economy due to their diffuse, unaccessible, and intermittent properties. Improvements in technology will be required before renewable energies are widely utilized, which should have a long way to go. Therefore, from short-term view, energy conservation is one of the feasible and effective solutions for energy and environmental sustainable development. Building cooling, heating, and power (BCHP) system is a novel energy system. Compared with conventional energy system, BCHP system can obviously improve efficiency of energy utilization because it provides heating and cooling services for building by recovering waste heat produced in the process of power generation. Increased efficiency of energy utilization decreases the amount of fossil fuel consumed per unit energy used and leads to reduction in air emission, and thus is useful for environmental sustainable development. In addition, BCHP can increase reliability of power supply and help improve indoor air quality (IAQ). Consequently, BCHP is a kind of sustainable development energy technologies, and energy-efficient technologies are desired.

China is the largest developing country in the world. The energy and environmental status in China have great effects on the world economic development. At present, China has an inappropriate energy structure, in which coal has a dominant position. Mass and inefficient production and consumption of coal in China brings about great environmental issues. Therefore, adjusting energy structure and improving energy utilization efficiency are important tasks in the process of China's development. It is significant to seek the way for China's energy and environmental development.

In this paper, environmental impacts of energy are briefly described, two solutions to energy and environmental sustainable development are reviewed and discussed systematically. BCHP technology and its sustainable characteristics regarding energy and environment are analyzed in detail. A general analysis of energy status in China is given and the prospects of BCHP in this country are studied.

2. Environmental impacts of energy

Rapid growth of the world economy brought about the rapid growth of energy demand. According to the research by IEA [7], the world energy demand will grow by 65% from 1995 to 2020 and the fossil fuel will still be in dominant position in future energy use. Many environmental problems, including air pollution, acid precipitation, ozone depletion, global warming, forest destruction, and radioactive substance, are all related to energy production and consumption to some extent. A comprehensive literature review about environmental impacts of energy use was given by Dincer [8] and a brief description about the three most important energy-related environmental issues is presented as follows.

2.1. Acid precipitation

Acids produced by the combustion of fossil fuels are released into atmosphere and can be transported over great distance through the atmosphere and finally come back to ecosystems on the earth via dry or wet precipitation. Fig. 1 is a schematic representation of the formation, distribution, and impacts of acid precipitation [4]. The effects of acid

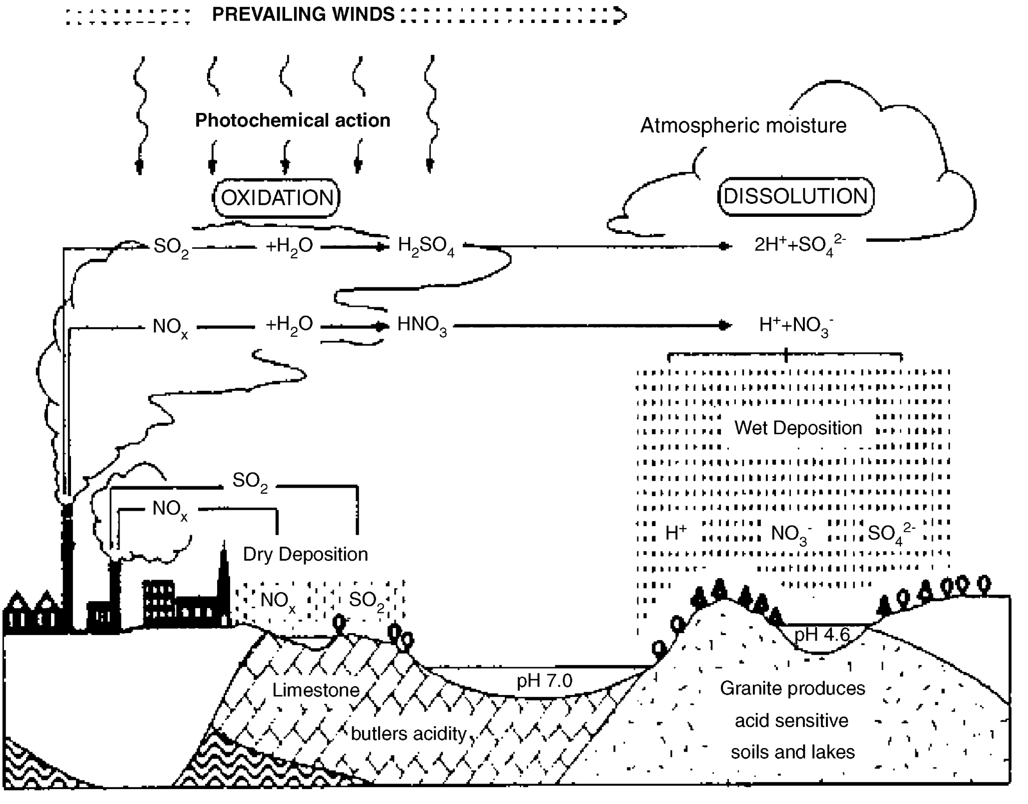


Fig. 1. Processes leading to acid rain (source from [4]).

precipitation include the following: acidification of lakes, streams, and ground water, resulting in damage of fish and aquatic life; damage to forests and agricultural crops; and deterioration of materials, e.g. buildings, metal structures, and fabrics.

Emissions of SO_2 and NO_X are main contributors of acid rain and other substances include volatile organic compounds (VOCs), chlorides, ozone, and trance metals. Some energy-related activities are major sources of acid precipitation. For example, electric power station, residential heating, and industrial energy use account for 80% of SO_2 emissions, with coal use alone accounting for 70% of SO_2 emission [9].

2.2. Stratospheric ozone depletion

Depletion of stratospheric ozone arises from destruction of ozone molecules in the upper atmosphere, primarily by bromine and chlorine from anthropogenic chemicals. Bromine and chlorine react catalytically to destroy ozone molecules, thereby reducing the natural shield for incoming ultraviolet-B radiation from outspace. Ozone depletion can lead to increased levels of damaging ultraviolet radiation reaching the ground, causing increased rates of skin cancer, eye damage of human beings, and other harms to many biological species.

Chlorofluorocarbons (CFCs), which are used in air conditioning and refrigeration equipment as refrigerants, and halons, which are used as blowing agents, are mainly responsible for ozone depletion.An international protocol was signed in Montreal to ban the production and use of CFCs and halons [10]. Compared with CFCs, Hydrochlorofluorocarbons (HCFCs) have less potential of ozone destruction.However, they will also be phased out by Montreal Protocol. Besides these substances, N_2O emission, which is energy related, can also cause destruction to the ozone layer. The index used to indicate the relative ability of a refrigerant or other chemicals to destroy ozone layer is the ozone depletion potential (ODP). The higher the ODP value, the larger the ability of ozone depletion. The ODP values of some substances are shown in Table 1 [10].

2.3. Global warming

The average temperature at the surface of our earth results from equilibrium between incoming solar energy and heat radiated back into space. Most of the latter is in the infrared range of emission. Increasing concentrations of greenhouse gases, such as CO_2, CH_4, CFCs, halons, N_2O, ozone, and others, in the atmosphere can increase the manner in which these gases trap heat radiated from the earth surface and raise the surface temperature of the earth. The earth's surface temperature has increased about 0.6 °C over the last century and, as a result, the sea level is estimated to have risen by perhaps 20 cm [4]. Such changes can have wide-range effect on human activities all over the world. Substances that cause global warming mainly include water vapor, CO_2, CH_4, N_2O, and O_3, among which CO_2, CH_4, and N_2O are energy related. Besides ozone depletion, CFCs, HCFCs, and halons also have high potential to result in global warming. Similarly, an index called global warming potential (GWP) was defined to indicate the ability of a chemical to warm global climate. GWPs of some substances calculated over 100 years time horizon are shown in Table 2 [11].

Table 1
ODP values of some substances

Chemicals	ODP	Chemicals	ODP
R11	1.0	R12	1.0
R13	1.0	R21	0.04
R22	0.055	Halon-1211	3.0
Halon-1301	10.0	Halon-2402	6.0

Table 2
GWP values of some substances

Chemicals	GWP	Chemicals	GWP
CO_2	1.0	R410A	2020
CH_4	21	R407C	1530
N_2O	310	R507	3300
R12	8500	CF_4	6500
R22	1400	C_2F_6	9200
R134a	1300	SF_6	23 900

3. Solutions to environmental issues

Two important solutions to the current environmental issues are renewable energy technologies and energy conservation by improving energy utilization efficiency [4].

Renewable energies, including solar, wind, falling water, tides, geothermal, and others, are key to achieve energy and environmental sustainable development. These energy resources have a massive energy potential and can ensure sustainable supply of energy. In addition, these types of energy resources have no or little impact on environment and thus are real clean energy. However, these types of energy resource also have many disadvantages, such as low efficiency of energy collection and conversion because they are generally diffuse, inefficiency in economy due to their high initial and maintenance costs, and bad reliability and applicability because of their intermittence. Therefore, improving energy conversion efficiency, increasing reliability of energy utilization, and lowering costs of energy use are three key factors to develop renewable energy.

At present, it is impractical to use renewable energy widely for technological, economical, and other reasons. Fossil energy will still be in a dominant position for a relatively long time. Therefore, energy conservation of using fossil energy through improved energy utilization efficiency may be a feasible and an effective way for energy and environmental sustainable development.

Increased efficiency of energy utilization can decrease the amount of fossil fuel consumed per unit energy used and can therefore lead to reduced emissions of greenhouse gases and other pollutions into the environment. High energy efficiency saves the energy resource and protects the environment as well, and thus benefits not only consumers and utilities but also society as a whole.

There exists great potential for improving energy utilization efficiency and achieving energy conservation. Increasing public awareness of energy conservation and making appropriate energy policy are two important ways for energy conservation. However, energy conservation must finally rely on energy-saving technology. Therefore, it is very important to study measures and ways of energy saving.

4. Building cooling, heating, and power

BCHP system, also referred to as combined cooling, heating, and power (CCHP) or trigeneration system, is an integrated energy system, which generates power sited at or near the building and utilizes waste heat produced in the process of power generation to drive thermally activated equipment and achieves supplies of cool, heat, and power for building simultaneously. Fig. 2 is the schematic diagram of a BCHP system. It consists of two subsystems, distributed power generation subsystem, and heat recovery subsystem. BCHP is suitable for buildings that have demands for both power and heat, such as office buildings, commercial buildings, hospitals, schools, restaurants, etc. In addition, for remote village, military buildings, and any other places where backup electric source is needed, BCHP system is also a good candidate.

4.1. Distributed power generation

Distributed power generation, also called field power generation, comprises power generation equipment, which converts chemical energy of fuel into electric energy, control

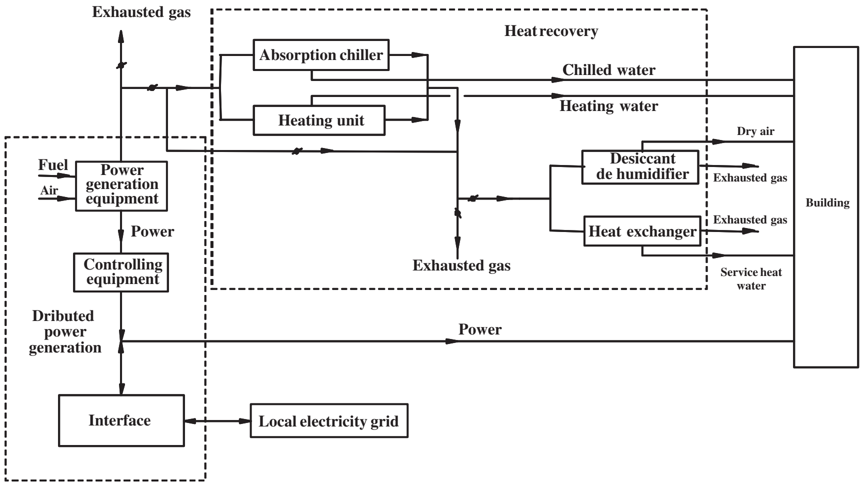


Fig. 2. Schematic diagram of building cooling, heating, and power system.

equipment of electricity, which converts voltage or frequency of power from generator into grid-quality power, and interface between distributed power generation system and local grid. Distributed power generation technologies used in BCHP system include microturbine (MT), fuel cell (FC), and internal combustion engine (ICE).

FC is a device in which hydrogen and oxygen combine without combustion to produce electricity in the presence of a catalyst. At present, four types of FCs developed and used in distributed power generation are proton exchange membrane fuel cell (PEMFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), and solid oxide fuel cell (SOFC). Among the three distributed power generation technologies, FC has the highest efficiency of power generation and also the highest cost. FC is, therefore, hard to compete with the two other technologies at present. Even so, FC has good prospects in future because of its advantages of high efficiency and low pollution emission. Moreover, the cost of FC will fall with mass production and improvement in technologies.

ICE, which operates Otto cycle, is the most traditional distributed power technology. The initial cost of ICE is the least but maintenance cost is the greatest among the three technologies. Its efficiency is lower and the emission is higher than the others. However, ICE is widely used in the world due to its low initial cost.

MT is a heat engine, which operates Brayton cycle. Efficiency of MT is good due to application of recuperator, which recovers the waste heat existed in exhaust gas to increase the compressed air temperature. The cost of MT is not high and its emission is modest. However, air bearings are desirable in order to reduce maintenance. Besides, MT has high-frequency noise problem because of its high rotary rate.

4.2. Heat recovery

The temperature of exhaust gas of distributed power generation is still very high and a large amount of thermal energy contained in exhaust gas can be reused. To improve the efficiency of energy utilization, waste heat in exhaust gas is recovered for heating,

air-conditioning, or humidity-controlling for buildings. Hot water or steam can be produced via waste heat recovery by using air-to-water heat exchanger and then be used not only to heat the building and/or supply service hot water directly but also to drive the absorption chiller to supply chilled water for buildings and/or regenerate solid or liquid desiccant for space humidity control.

From thermodynamic viewpoint, absorption chiller operates similar refrigeration cycle as electric compression chiller does. However, the primary energy sources they use are different, which is electricity for electric compression chiller while thermal energy for absorption chiller. Therefore, absorption chiller can be driven by recovered waste heat from exhaust gas of power generation. In contrast to compression chiller, the refrigerant of absorption chiller is CFCs or HCFCs free. The absorption cycle employs two working fluids, the absorbate or refrigerant, and the absorbent. The most commonly working fluids are water as refrigerant and lithium bromide as absorbent. According to the number of generator, absorption chiller can be sorted into single effect, double effect, and multiple effect. The COP of double-effect chiller is higher than that of single effect, but the temperature of heat source demanded for double effect is also higher than that for single effect. Multiple-effect absorption chiller is still in research period. It has not yet been commercialized.

To keep a comfortable indoor climate, it should control relative humidity of indoor air under certain level besides a favorable indoor air temperature. Cooling dehumidification, which uses chilled water whose temperature is lower than dew point temperature of air to condense the water vapor in air, is widely used in conventional air-conditioning system. However, the dehumidified air is rather cold and should be reheated before it is delivered into air-conditioning room and thus consumes excessive energy for this process. In addition, the COP of chiller lowers with decrease of supply water temperature.

Besides cooling dehumidification, desiccant can be used to dry supply air. Moist air is dried when it flows through the desiccant. Desiccant will lose its ability of dehumidification with increase of its moisture. In order to dehumidify the passed air continuously, the desiccant is regenerated using dry air with higher temperature. Therefore, heat energy will be consumed to regenerate desiccant. Energy conservation will be achieved if waste heat recovered from exhaust gas of power generation is used to regenerate desiccant.

Desiccant can be sorted into solid desiccant, such as active carbon, silica gel, $CaCl_2$, and liquid desiccant, such as solution of $CaCl_2$ or LiCl. All these solid and liquid desiccants have good dehumidifying ability and thus are widely used.

5. Sustainability of BCHP

5.1. Energy sustainability of BCHP

In conventional energy-generation system, electricity is generated in central power plant via combustion of fuel and is then delivered to users over high-voltage transmission grid and lower-voltage distribution grid. In the processes of electricity generation and transmission, at least two-thirds thermal energy generated by fuel combustion is released into surroundings without being reused. On the other hand, in order to meet the requirement for space conditioning of buildings, fuel-driven boiler or electricity-driven chiller sited at or near the building must be used, which consumes great deal of energy. Usually, the thermal energy conversion efficiency of boiler is only 80–90% and thus the

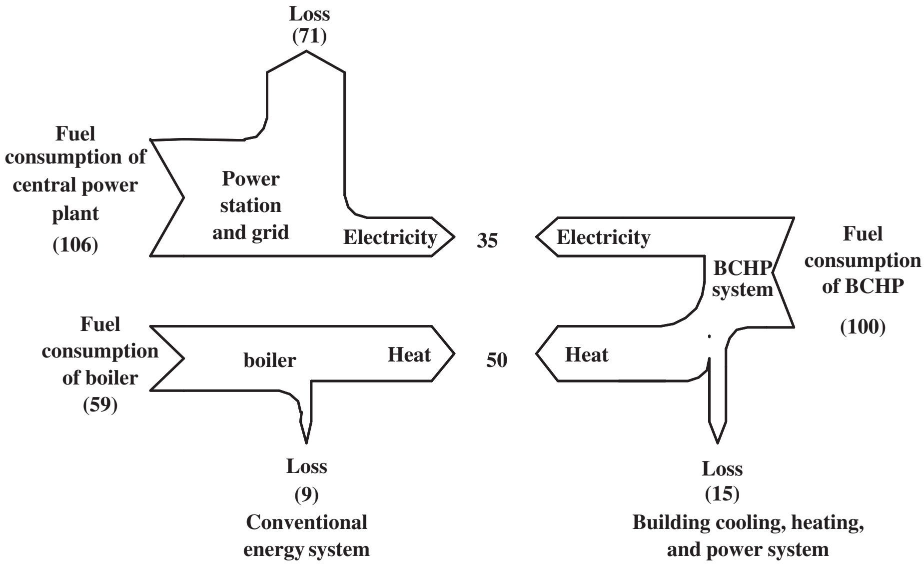


Fig. 3. Comparison of energy conversion efficiencies for BCHP system and conventional energy system.

energy utilization efficiency of conventional energy-generation system is just 49–56% [12]. In contrast, BCHP system generates power at or near the buildings and supplies to buildings directly. Therefore, electricity loss in transmission and distribution grid can be reduced greatly. In addition, BCHP system utilizes waste heat from power generation, which is gone to waste in conventional system, to meet the requirement of building space conditioning. Therefore, compared with conventional energy system, BCHP has higher energy utilization efficiency. Usually, a 35% power generation efficiency and 50% heat recovery efficiency can be gained and thus the overall efficiency of energy use can reach 85%. Consequently, BCHP system can reduce 40% primary energy consumption than conventional energy system. Fig. 3 is the comparison of energy conversion efficiencies for the two kinds of energy systems [13]. It can be seen from Fig. 3 that BCHP system can obviously improve the energy utilization efficiency, reducing the consumption of energy resource. Therefore, BCHP can achieve energy conservation and is useful for energy sustainable development. Besides a higher energy utilization efficiency, the primary fuel used by BCHP system is different from that used by conventional energy system. In the conventional system, coal is usually used as fuel burning in central power plant or heating boiler, while natural gas is often used by MT and FC in BCHP system. Natural gas is a kind of cleaner energy as compared to coal. Therefore, developing BCHP technology is also useful for improving the proportion of clean energy in energy consumption, especially for countries where coal is in dominant position in energy structure.

5.2. Environmental sustainability of BCHP

As discussed above, BCHP system increases overall efficiency of energy utilization from 51% for conventional system to as high as 85%. Therefore, the use of these systems reduces the consumption of fossil fuels for a unit of energy required for buildings by close

to 40% of that used by conventional systems. This also means that for every unit of energy consumption, BCHP system can reduce emission of pollutants by about 40%. In addition, the pollutants emission rate of BCHP with combustion of natural gas by MT or FC is very low; for example, the emission concentration of NO_X for MT is lower than 10 ppm and that for FC is lower, which is not higher than 1 ppm. Decrease of pollutants emission can reduce occurrence of acid rain and weaken global warming. Moreover, BCHP system uses absorption chiller to supply chilled water with CFCs- or HCFCs-free refrigerants, which reduces the risk of ozone depletion. Therefore, BCHP is very useful for environmental protection.

Besides improving outdoor environmental quality, BCHP system also provides a valid way for improving IAQ and indoor comfort. A low air relative humidity can help prevent the growth of mold and bacteria which are harmful for residents' health. Desiccants can be used to control the indoor air humidity, but it will consume heat to regenerate desiccant [14]. However, BCHP can support the use of desiccant dehumidification system to dry air by providing waste heat from power generation to regenerate desiccant. Therefore, combined with desiccant humidification system, BCHP can achieve the unity of improvement of IAQ and conservation of energy.

5.3. Reliability of power supply

Energy is the most significant driving force of the world economy. All buildings need electricity for lighting and operating equipment. Power outage can bring huge loss for enterprises besides having side effect on living of people. Developing BCHP can help relieve the pressure from power shortage and bring vigor for economy increase. Wide usage of air-conditioning equipment driven by electricity brings sharp peak load in hot summer or cold winter, which exerts a huge pressure on power station and transmission and distribution grid for increasing capacity. BCHP system has good ability to shift peak load and cut off the sharp peak of power load. Moreover, BCHP can also reduce the disequilibrium in use of natural gas in summer and winter. Because power generation equipment is at or near the building site, BCHP can eliminate the blackouts of transmission network that results from natural disasters, such as storms, earthquake, etc., and thus can help improve power reliability.

6. Status of energy in China

As the largest developing country, status of energy in China has a great effect on environment. For a long time, China has an inappropriate energy structure, in which coal plays a dominant role and clean energies, such as hydropower and natural gas, have a very small percentage. Figs. 4 and 5 are the percentages of China's primary energy production and consumption from 1990 to 2000, respectively. It can be found from Figs. 4 and 5 that the percentages of coal in primary energy production and consumption decreased slowly from 74.23% and 76.19% in 1990 to 67.20% and 67.00% in 2000, respectively. At the same time, oil, natural gas, and hydropower in production have a slight increase by 2.39%, 1.44%, and 3.20%, respectively, while those in consumption have a small rise of 6.98%, 0.45%, and 1.76%, respectively. Even so, the ratios of clean energy in China's energy structure are still far behind the average level of the world, just as shown by Fig. 6.

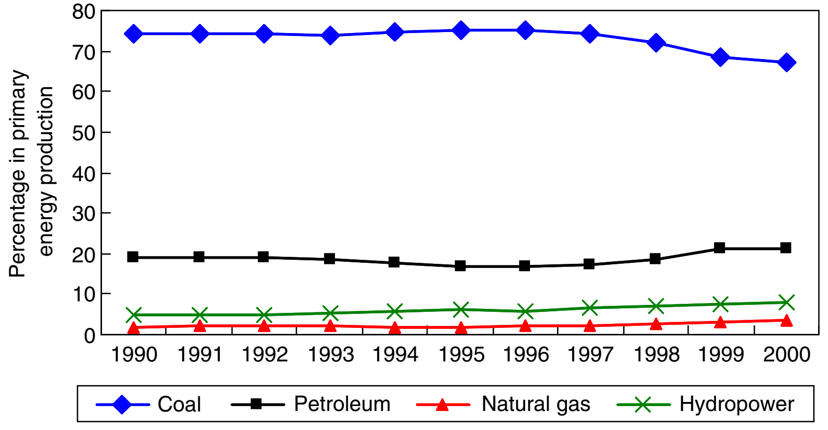


Fig. 4. Percentages of various energies in China's primary energy production from 1990 to 2000. Note: data in Fig. 4 sources from China Statistic Abstract (2001).

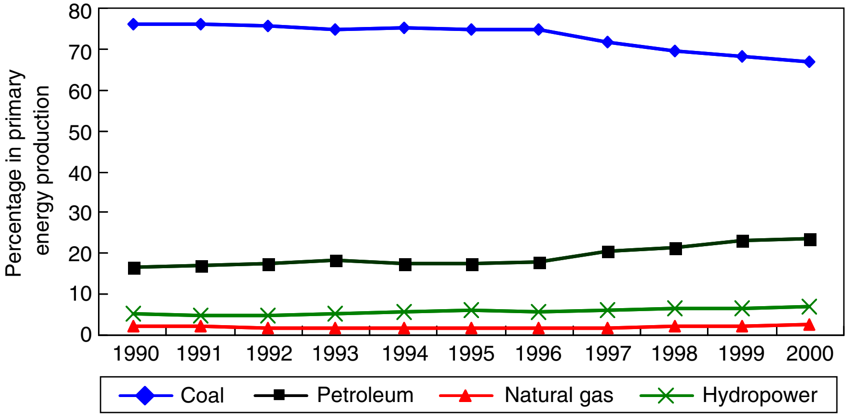


Fig. 5. Percentages of various energies in China's primary energy consumption from 1990 to 2000. Note: data in Fig. 5 sources from China Statistic Abstract (2001).

Therefore, improving energy structure via decreasing the percentage of coal in energy production and consumption is quite a task for the country's development.

Besides an inapt energy structure, energy efficiency in China is also very low for laggard technologies and aging equipments. The energy efficiency in that country is only 32%, which is 10% lower than that of the developed countries [15]. A comparison of energy efficiency for major energy-consumed equipments between China and developed countries is illustrated in Fig. 7. Energy consumption per unit output of main industrial products is 12–55% higher than that of the developed countries. Energy consumption per unit power generation is 405 g(coal)/kWh, which is 26.5% higher than that of advanced level in the world of 320 g(coal)/kWh [16].

In the developed countries, buildings consume about 30–40% energy in their yearly energy consumption. Table 3 shows the ratios of energy consumed in buildings sectors in

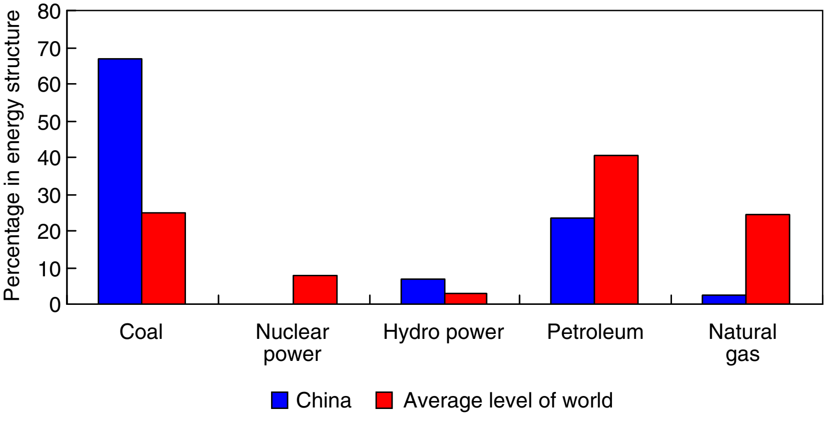


Fig. 6. Comparison of energy structure between China and the World.

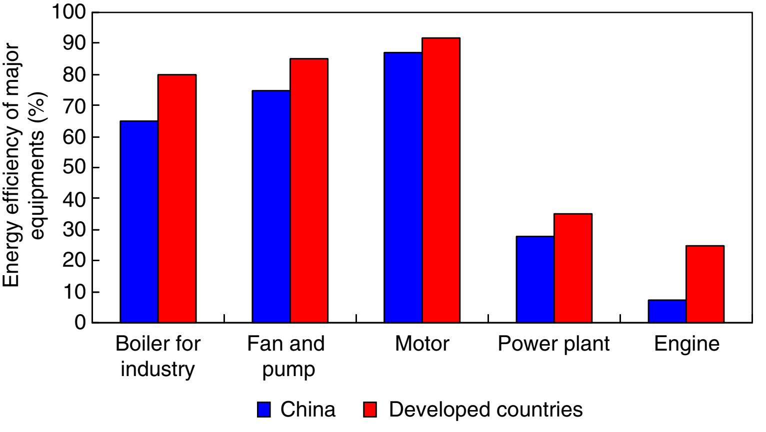


Fig. 7. Comparison of energy efficiency between China and the developed countries.

Table 3
Ratios of building energy consumption in total energy consumption in some countries

Nation	USA	UK	Sweden	Denmark	Netherlands	Italy	Canada	Belgium
Ratio	31.9	34.3	33.9	42.4	33.9	27.4	31.8	31.8

some countries. During the recent years, building energy consumption in China has increased rapidly as a result of quick development of cities. Building energy accounts for about 20% of the total energy consumption, 85% of which goes to HVAC systems in buildings [17].

Among most of China's large cities, room air conditioner and central air-conditioning system are becoming increasingly popular, most of which are driven by electricity. Fig. 8 shows result of survey conducted on cooling sources of 200 buildings in Shanghai, the

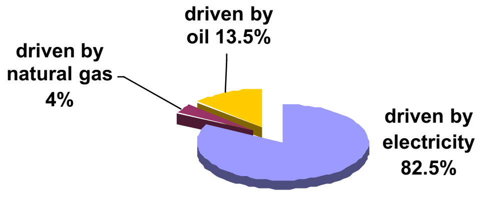


Fig. 8. Result of survey for cooling sources of 200 buildings in Shanghai.

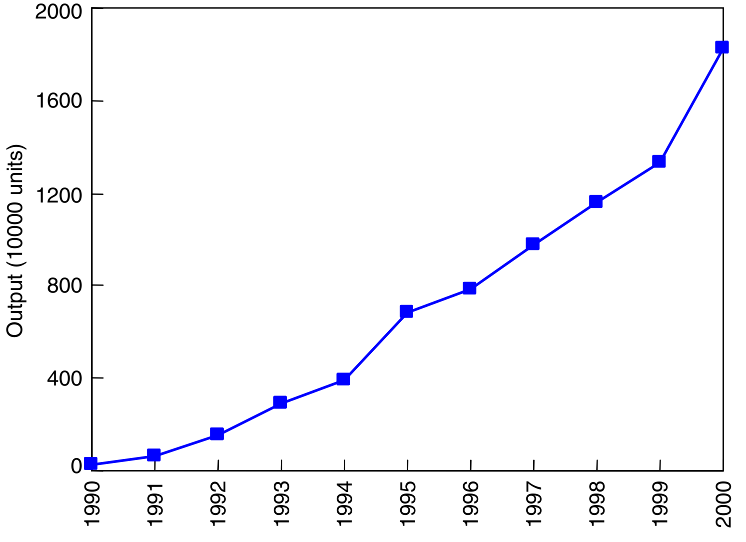


Fig. 9. Output of room air conditioner from 1990 to 2000 in China.

biggest city in China [18]. Room air conditioner is widely adopted in residential buildings in China. The proportions of air-conditioned families in Shanghai, Chongqing, and Guangdong province are 68.2%, 68.33%, and 71.5%, respectively [19]. Many families even have more than one set of air conditioner. At the same time, the output of room air conditioner increases rapidly these years. Fig. 9 describes such tendency from 1990 to 2000. Central air-conditioning system is becoming more popular, whose conventional energy source is also electricity.

The wide use of electricity-driven air conditioner and central air-conditioning system leads to the rapid increase of electricity consumption. In many cities, electricity consumption for air conditioning accounts for one-third of the total electricity consumption, which has enlarged the gap between peak load and off peak load of electricity supply. Sharp peak load exerts a huge pressure on electricity supply. In summer in 2003, more than 19 provinces out of 31 provinces of China had to overcome shortage of electricity by rolling blackout.

In general, building energy efficiency in China is rather low. At current stage, scientific and systematic index for evaluation of building energy efficiency has not been adopted in China.

The index adopted is energy consumption per unit floor area, which is a static index. So far as HVAC system in China is concerned, most of them adopted peak load in design process, and technology for energy saving is not adopted popularly among them, as a result it makes energy efficiency of HVAC systems quite low. Therefore, with the present status of energy in China, it is necessary to modulate energy structure of China, increase the proportion of clean energy in energy structure, improve energy utilization efficiency, and decrease energy consumption, especially building energy consumption. To achieve this aim, innovative, energy-efficient, and sustainable energy production and utilization technologies are desired.

7. Prospects of BCHP in China

Coal's dominant position in China's energy structure is one of the main reasons resulting in bad environmental quality. According to Chinese Environmental Protecting Bureau, the total amount of SO_2 emission in 2000 is 1995 ton, which ranks the second in the world and just behind America. In 238 cities of China, which have environment monitoring sets, the atmosphere quality of 63.5% of them is worse than the second stage of national standard. Acid rain occurred in 61.8% of cities in south of China. From the above facts, it can be found that there is an urgency to adjust China's energy structure by reducing proportion of coal and increasing proportion of clean energy, such as natural gas and hydropower, in energy structure. It is also necessary for China's energy and environmental sustainable development to adopt advanced technologies and equipments to improve energy efficiency and implement policy of energy conservation widely.

BCHP, usually using natural gas as primary energy, can help China to adjust its energy structure and finally protect the environment of the country. As an energy-efficient technology, BCHP can save primary energy consumption for China, and thus is useful for energy sustainable development. In addition, BCHP system can peel the sharp peak of electricity load and alleviate the shortage of electricity by using waste heat to space conditioning, so that more electricity can be supplied to industrial sector, which accelerates economic development. Moreover, BCHP can improve electric structure of China and increase reliability of electricity supply. For a long time, the mode of electricity supply in China is a kind of central supply with central power plant and large electricity transmission and distribution grid, which is devoid of reliability. BCHP is a kind of distributed power generation system and, therefore, can improve security of power supply. Chinese government is conscious of the necessity and urgency of adjusting energy structure and improving energy efficiency. Some policies and stratagem are implemented to achieve this aim. The national level project called Transporting Western Gas to the East, aiming to transport natural gas from west to east through pipe system, is under way and is expected to finish by 2005. Importing natural gas from Russian, Kazakstan, and Turkmenistan by pipe and importing liquidized natural gas from sea by ship are also in plan. All these stratagems will help in improving the proportion of natural gas in energy structure and create conditions for the development of BCHP in China. We can be sure that BCHP technology will have broad prospects in China.

8. Conclusions

During the last century, as environmental degradation became more and more serious with rapid growth of the world economy, it is desirable to achieve environmental

sustainable development. Many significant environmental issues are all energy related directly or indirectly, and thus achieving energy sustainable development is one of the prerequisites for environmental sustainable development.

Renewable energy technologies and energy conservation are two potential solutions for energy sustainable development. For economic, technological, and policy reasons, it is impractical to use renewable energy widely at present, though it may be a final solution for energy and environmental sustainable development. Therefore, energy conservation through improving energy utilization efficiency may be one of the feasible and effective solutions for energy and environmental sustainable development at present.

BCHP is a kind of energy-efficient technology. Compared with conventional energy system, it has higher energy utilization efficiency due to utilization of distributed power generation technology and heat recovery technology. BCHP has a power generation efficiency of 35% and a heat recovery efficiency of 50% and consequently an overall efficiency of 85%. It can reduce primary energy consumption by about 40% and thus can reduce pollutants emission at the same proportion. Moreover, BCHP can help improve IAQ and increase reliability of power supply. Because it often uses natural gas as the primary energy, BCHP technology can also increase the proportion of natural gas in energy structure. Therefore, BCHP is a kind of sustainable technology, and developing BCHP can promote energy and environmental sustainable development.

It is necessary and urgent for China's energy and environmental sustainable development to adjust its inappropriate energy structure and increase its energy utilization efficiency. As a kind of energy-efficient technology, BCHP is useful for optimizing energy structure, lowering energy consumption, and protecting environment. BCHP technology will have wide application in China.

Acknowledgments

This work is financially supported by the Teaching and Research Award Program for Outstanding Young Teachers in Higher Education Institutions of MOE, PR China (Project no. [2002] 383), and Hunan Provincial Natural Science Foundation of China (Project no. 05JJ40071).

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